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UPGRADING AND MAINTENANCE OF

CANMET'S RADIO TELEMETRY SYSTEM

FINAL REPORT

TO

CANMET
MINING RESEARCH LABORATORIES,
WESTERN OFFICE,
ENERGY, MINES AND RESOURCES
DEVON, ALBERTA

BY

ECOLOGICAL AND RESOURCES CONSULTANTS LIMITED

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PREFACE

This is the final report for Contract No. 23440-6-9023/01SQ. covering upgrading and maintenance of CANMET's radio telemetry system, submitted to CANMET, Mining Research Laboratories, Western Office, Department of Energy, Mines and Resources, Devon, Alberta.

The responsibilities for this project were shared among four consultants of Ecological and Resources Consultants Ltd., in Fredericton, N.B., each dealing primarily with the aspect most suited to his technical expertise.

Other technical and general support was provided as needed.

Fredericton, N.B.
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ABSTRACT

Between August 1985 and February 1986, CANMET's tiltmeter/telemetry system with five slave stations underwent field tests at Syncrude's oilsands mining operation near Fort McMurray. The purpose of the tests was to investigate a possible adaptation of the system to monitoring the stability of high walls in the dragline operation and of the tailings dyke in this difficult industrial environment and under severe climatic conditions. While the initial tests provided favourable results, some improvements, which are the subject of this report, were required to better adapt the system to the peculiar needs of the Syncrude operation.

In particular, a slave had to be modified to accommodate borehole inclinometers, transmission had to be improved because of the longer distances involved and poor intervisibility with the master station, and an extended maintenance and testing programme had to be carried out. Furthermore, a quick guide to the Ecological and Resources Consultants Limited telemetry software and hardware was prepared, and enchancement possibilities for a new generation telemetry system were provided.

ACKNOWLEDGEMENTS

The Consultants wish to acknowledge with thanks the efforts of the following persons whose contributions were invaluable to the success of this project:

- Dr. N. Stewart, the Scientific Authority, who was extremely supportive throughout the project.
- G. Holmes, chief of the geotechnical group at Syncrude and his staff, particularly T. Stevens, who closely cooperated in the field tests and supplied valuable information on the monitoring needs.
- Research assistants at the University of New Brunswick, particularly J. Secord, who participated in the calibration of inclimometers.
- Dr. A. Zielinski of the University of Victoria who served Ecological and Resources Consultants Limited as an external consultant.

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1. INTRODUCTION

The Coal Research Laboratory of the Canada Centre for Mining and Energy Technology (CANMET) in Devon, Alberta, conducts surface mining research in western Canada. In the process an instrumentation system has been developed by Ecological and Resources Consultants Ltd. (ERCL, hereinafter referred to as the Consultants)) of Fredericton, N.B., to monitor surface subsidence over an underground mine located in the mountains. The hostile climate and terrain conditions led to a unique system consisting of biaxial tiltmeter sensors coupled to "slave" radio transmitters, and a remote "master" receiving station to process and store data [ERCL, 1980; 1983]. The "master" station can be programmed to interrogate slaves by various criteria, e.g., time, amount of movement, etc., so that a continuous watch is obtained without continuous operation. The radio telemetry system has a capacity of 256 channels and may be used with any sensor having an appropriate electrical output. The tiltmeter responds to small changes in inclination of the ground to which it is anchored. A series of ground tilt measurements can be used to calculate subsidence. There is reason to expect that inclination measurements might be more widely used to monitor ground movement arising from mining advance in other situations.

Two ground stability problems have been identified as warranting priority attention in oilsands mining. One of these is the need for more assurance of the security of the dragline working bench. Shallow (20 m) block slides occur along thin clay bands located near the top of the oil bearing information; the crest of the highwall including the bench from which the dragline would operate may slide into the excavation. Since total mine production comes from four draglines, the loss of one of these multi-million dollar machines would have obviously serious consequences to the plant. Hence, elaborate precautions are taken to locate and monitor the status of potential zones of weakness in the working bench. A critical element in the existing monitoring program is the measurement of shear displacement in boreholes located along the line of advance of the production dragline.

The measurements are made manually by scanning the boreholes with inclinometers. For safety reasons, the dragline operation must be stopped whenever borehole measurements are in progress in its proximity. Thus the monitoring surveys are expensive, discontinous, and sometimes hazardous for the survey crew. Adaptation of the telemetry system to remote data acquisition with in-place inclinometers or tiltmeters would certainly improve the monitoring process.

Security of the tailings dyke is another problem. The tailings dyke at one property is some 20 km long of which about half is located on a foundation of till underlain by marine clay. Lateral movement at the dyke (outward from the basin) occurs in the clay bed. Long-term measurement of this movement may serve as an indicator of dyke stability and as a basis for specifying the safe height for the tailings dyke. Tilt measurements at the toe of the dyke could provide an indirect measurement of lateral movement in the clay seam.

The 1985 field trials of CANMET's radio telemetry system have successfully demonstrated the ability to monitor tiltmeters at both the highwall and tailings stations of the Syncrude Open Pit Oilsand Mine near Fort McMurray, Alberta. A comment from Syncrude personnel, quoted in the Consultants' report [ERCL, 1986] summarizes the system's evaluation:

> The system has two big advantages to the current slope monitoring system. First, there is an oppportunity to substantially reduce the amount of labour and time required to utilize our current system. Secondly, the telemetry system will provide an

opportunity to obtain continuous data. In our opinion, the system has tremendous potential and is definitely worthy of further testing.

The Consultants subsequently prepared a number of modifications and improvements to the telemetry system so that it meets the needs of Syncrude Canada Inc. even better. As a result, in June 1986, CANMET awarded a contract to ERCL for "upgrading and maintenance of CANMET's radio telemetry system".

2. STATEMENT OF WORK

The objective of this contract was to upgrade and provide maintenance for CANMET's radio telemetry system operating at Syncrude's oilsands open pit mine located near Fort McMurray, Alberta.

The work statement as specified in point form in the contract has been directly adopted from the Consultants' proposal, dated 9 April 1986. Both the short statement listed in the contract and the more detailed interpretation as found in the proposal are repeated here for the sake of completeness:

1. Modify four slave stations to make them compatible with the slope inclinometers.
2. Improve transmission of data between slaves and master station to cover extended distances above 5 km.
3. Provide trouble-shooting, maintenance advice for the period of six months including at least three visits to Fort McMurray, Alberta.
4. All visits must have prior written approval of the Scientific Authority.
5. Prepare a feasibility study on the redesign and construction of new generation telemetry equipment to replace six-year old equipment.

The additional information as given in the proposal is as follows.

To item #1:

It is anticipated that this aspect can be carried out within the given budget if the output voltage of the inclinometers is similar to that of the tiltmeters which are presently hooked up to the system. If, however, large discrepancies exist which would require expensive amplification or other conversions, the adaptation would then only be attempted for one slave station to illustrate the capabilities of the system.

Initially, we had proposed to make the slaves more versatile by providing hook ups for up to six different sensors (see our preliminary proposal), but unfortunately the restricted finances will not permit major reconstruction of the slaves.

To item #2:

Again, financial constraints prohibit the purchase of more powerful transmitter-receiver units, as well as of thermostat controlled heaters for cold weather operation. Instead, it is proposed to equip each slave unit with an antenna relay, thus utilizing the available directional antennas for alternate transmission and reception.

In addition, a surge protector will be installed at the master station to avoid partial loss of operating software and thus down time due to surges in the electrical power supply. It is, however, not possible within the proposed financial limits to protect the system against power outages.

To items #3 and #4:

These items will be fully covered as requested. Approval for the visits will be sought from the Scientific Authority. It is planned to perform a thorough systems calibration and adjustment during the first visit.

To item #5:

This will be done as requested. It is planned to present this during the debriefing seminar.

The contract specified the requirement for the debriefing session:

After submission and acceptance of the final report, the contractor shall prepare a verbal presentation outlining the problems and successes associated with the work and present this material in a one-day debriefing session to CANMET representatives and interested outside parties. The time and location (usually Edmonton) of the presentation will be at the discretion of the Scientific Authority who may also decide that the work does not warrant presentation.

3. ADAPTATION OF INCLINOMETERS TO THE TELEMETRY SYSTEM

3.1 Assessment of the Problem

In June 1986, the Consultant received one of the inclinometers from Syncrude Canada Ltd. for testing and adaptation to the slaves.

Initial tests revealed the following items to be addressed in order to successfully adapt the inclinometers to the telemetry system:

- the measuring ranges of inclinometers and tiltmeters are incompatible thus requiring signal amplification,
- the inclinometer cable is equipped with a special and rather expensive connector,
- the inclinometer requires a thorough calibration in order to determine the conversion factor between output voltage and amount of inclinations in degrees of arc,
- in order to provide for inclinometer output on separate channels without interfering with the tiltmeter output, hardware changes to the slave are necessary,
- software changes in response to the new conversion factor and output signals on different channels need be incorporated.

In light of this and with agreement of the Scientific Authority, it was decided to carry out the hardware modifications for one slave only, rather than modifying more slaves at the expense of virtually everything else in the contract. As indicated in section 2 of this report, this is in agreement with the detailed proposal submitted by the Consultants as it clearly demonstrates the capabilities of the system.

Furthermore, by attaching the unit containing signal amplification and the connector conversion to the inclinometer units, it is possible to operate them together with any slave. The output signals for slaves with the old (unchanged) hardware configuration will then be obtained on their tiltmeter channels, thus preventing the use of both measuring instruments at the same time. This limitation is of little practical consequence because usually either tiltmeters or inclinometers are utilized.

3.2 Amplification of Inclinometer Signals

The inclinometers used by Syncrude Canada Ltd. are of a servo-accelerometer type produced by SINCO Co. The ranges of inclinations are either ±30° or ±53°, depending on the model. The range of output signal is typically ±12V.

The telemetry system was originally designed for use with tiltmeters whose useful range was only ±1°. The input range of the system's analogue to digital converter is ±5V which corresponds to ±128 bits. The input range dictates the resolution of the system which in the case of the tiltmeters gives ±1°/128 = 28 seconds of arc.

The required sensitivity of the borehole inclination measurements is about 1 mm/m, or 0.002'/2' when measurements are carried out with a two-foot long inclinometer. This corresponds to about 200 seconds of arc. Thus, when connecting the inclinometer with ±53°/12V range directly to the slave unit of the telemetry system, its resolution would be only 53° (5V/12V)/128 = 620" (seconds of arc). Therefore, the adaptation of the inclinometer requires an amplification of its output signal by a factor of about 3.5. This produces a problem because the useful measuring range of the

inclinometer is then reduced from ±53° to only (53°/3.5)(5V/12V) = ±6°.

The Consultants decided that for the purpose of testing the usefulness of the telemetry system for borehole measurements, it was better to maintain the required sensitivity rather than the large inclination range. Therefore, a 3.5 amplification has been applied.

In order to allow for the flexibility of using the telemetry system with different sensors of different amplification requirements, an external amplification was applied. Therefore, the amplifier was built into a separate box with connectors to both the slave unit and to the inclinometers (Figure 1).

3.3 Connection of Inclinometers to the Slave Units

The slave units of the telemetry system and cables of the tiltmeters are equipped with standard Amphenol connectors which are inexpensive (approx. $30/set) and readily available. However, the inclinometers used by Syncrude Canada Ltd. required special Lemo type connectors which are rather expensive ($240/set) and had to be ordered from SINCO, the producer of the inclinometer. In light of the high cost it was decided to limit hardware changes to only one slave unit (No. 6) as mentioned earlier. In order to maintain the aforementioned flexibility of the telemetry system, the Lemo connector was thus applied only to connect the inclinometer to the amplifier box while additional Amphenol connectors were used to connect this amplifier box to the slave unit. Thus, either tiltmeters or inclinometers can be connected to the same channel of the slave unit without requiring expensive hardware changes. It is, however, necessary to make the proper software changes (new conversion factor, based on inclinometer calibration data).

3.4 Inclinometer Calibration and Determination of Voltage/Inclination Conversion Factor

The inclinometer probes which are used by Syncrude Canada are of the servo-accelerometer type with the output signal (voltage) proportional to the sine of the angle of inclination. Their angular resolution in the inclination measurements is about 100 seconds of arc in the near vertical position which corresponds to about 0.001 foot (0.3 mm) of linear tilt at the top of the probe with respect to its bottom (the total distance between the top and bottom guide wheels is 2 feet).

Due to the amplification introduced and uncertainty of the functional relationship between the inclination and output voltage, the Consultants had to conduct their own calibration of the inclinometer which was intended for use with the telemetry system.

A special calibrator unit (Figure 2) was designed and constructed for that purpose. The calibrator's angular resolution proved to be better than 20 seconds of arc. Figure 3 shows calibration results with inclinometer No. s/n 25 638 which was previously supplied by Syncrude to the Consultants. The conversion factor (including the 3.5 amplification) was found to be 0.882 [v/degrees of arc] with a good linear relationship for the total operating range of ±6° which had been expected since the sine function for this comparatively small range may be treated as a linear function within the accuracy of the resolution of the system.

Since a different inclinometer (No. 5) was eventually to be used in the field test, rather than the inclinometer calibrated in Fredericton, the calibrator was taken to the Fort McMurray site in August 1986. At the site, the Consultants found out that Syncrude's electric shop had its own calibrating unit, although of a different design, with only a slightly worse resolution than the Consultant's calibrator. It was therefore decided to use Syncrude's calibrator. In Figure 4 the results of the calibration for axes A and B of inclinometer No.5 are listed. The results again show good linearity with a mean conversion factor of 0.852 [v/degrees of arc], which the same for both axes.

CONNECTING DIFFERENT SENSORS TO SLAVE

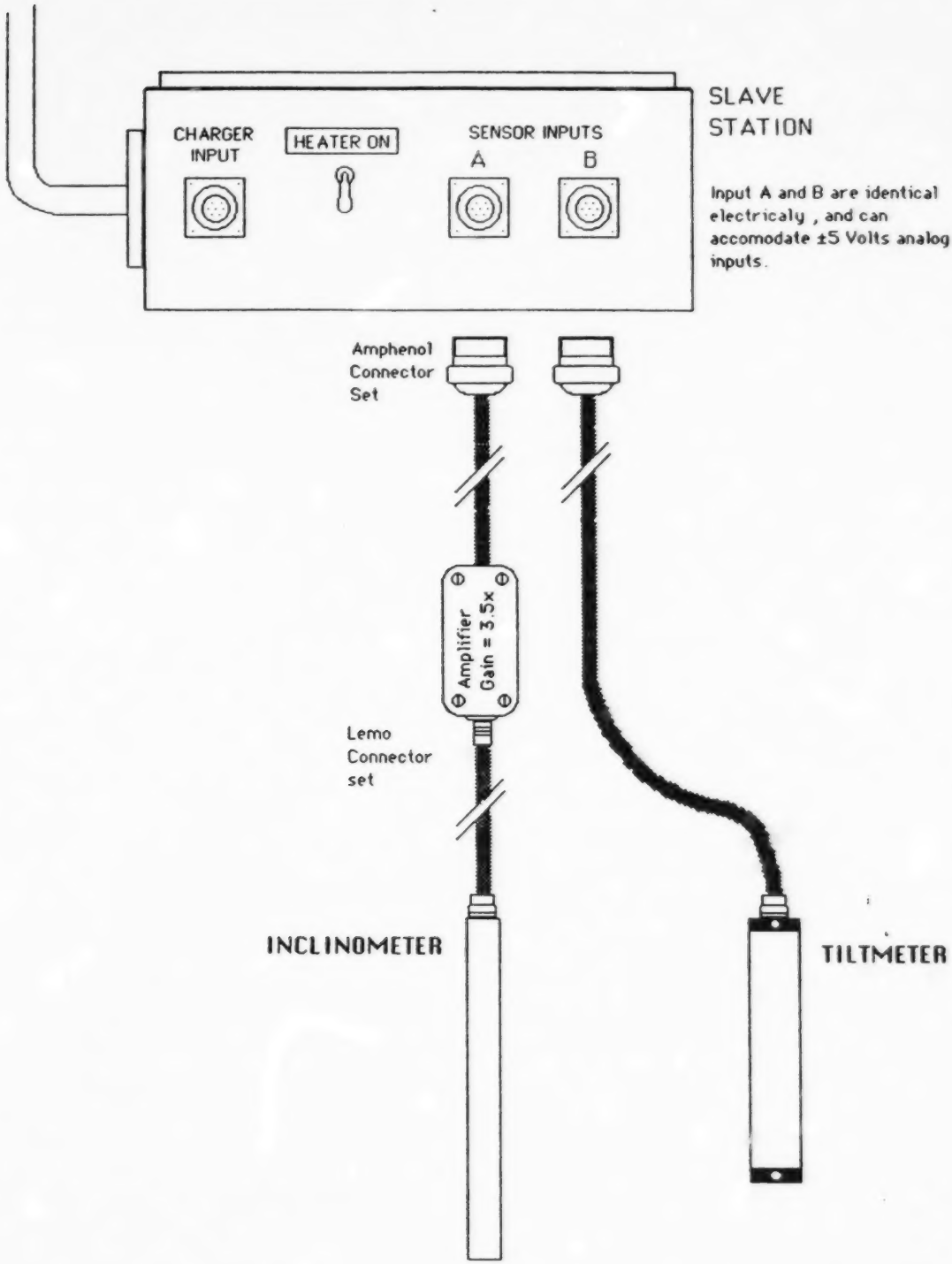


Figure 1

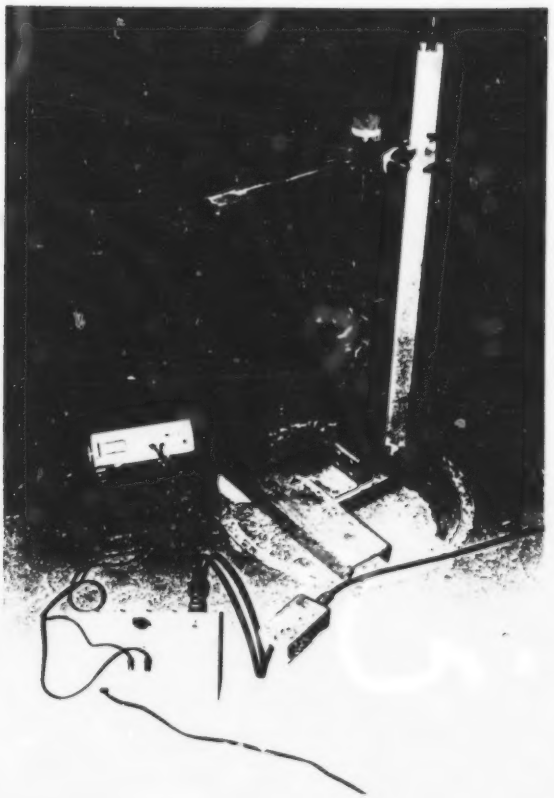


Figure 2

Special calibrator.

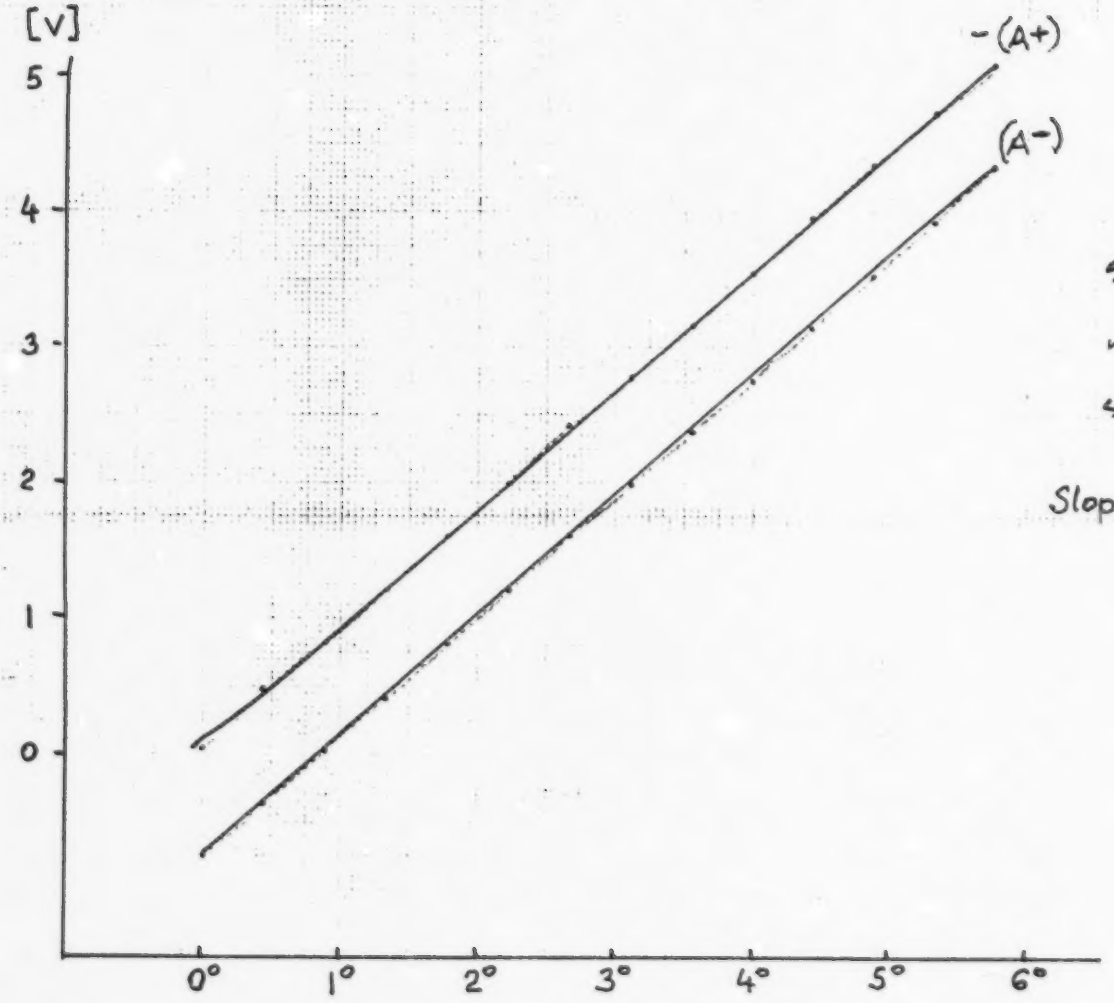


FIG. 3.

CALIBRATION RESULTS:

SINCO model 50325-M sensor
with 3.5 gain amplifier
sensor s/n 25638

Slope: 0.882 [V/°]

Inclination in degrees	Axis A [V]	[ΔV]	Axis B [V]	[ΔV]
0°	-0.185		-0.187	
		0.856		0.843
1°	0.671		0.656	
		0.865		0.859
2°	1.536		1.515	
		0.851		0.851
3°	2.387		2.366	
		0.855		0.855
4°	3.242		3.221	
		0.848		0.849
5°	4.090		4.070	
0°	-0.185		-0.188	
		0.850		0.854
-1°	-1.035		-1.042	
		0.852		0.853
-2°	-1.887		-1.895	
		0.856		0.845
-3°	-2.743		-2.740	
		0.847		0.840
-4°	-3.590		-3.580	
		0.860		0.850
-5°	-4.450		-4.430	
		0.850		0.850
-6°	-5.300		-5.280	
	Mean:	0.854	Mean:	0.850

Figure 4
Calibration results for Syncrude Inclinometer No. 5

Since the geotechnical group at Syncrude wanted to have readouts of the inclinometer in hundreds of a foot per two feet, the voltage output had to be multiplied by a factor of 4.1 calculated as $(1° \times 100 \times 2' \times \pi) / (0.852 \times 180°) = 4.097 \cong 4.1$. The above factor was introduced in the computer programme of the master station to convert the voltage signal coming from the inclinometer to the corresponding input channels of the master station (slave #6, channels 4 and 5).

3.5 Hardware and Software Modifications of Slave Unit

The special unit which combines signal amplification and connector conversion enables the attachment of an inclinometer to any of the slaves by utilizing the entry port previously used for tiltmeter connections.

By modifying the operating software to account for the new conversion factor (see section 3.4), the output that is transmitted from the slave via the telemetry link represents now inclinations in hundreds of a foot per two feet rather than tilts in seconds of arc. If, however, both tilts and inclinations are to be measured and the respective signals transmitted to the master station, hardware and software modifications are necessary.

The hardware modification was carried out on site in August 1986 when Syncrude's inclinometer No. 5 was adapted to slave No. 6. The work consisted of building a separate entry port for the cable coming from the amplifier/connector box which, in turn, can be connected to an inclinometer with the already mentioned Lemo connectors. This entry port is hard-wired into the slave system. At the same time, the antenna mast of slave No. 6 was replaced to provide for more rigidity during transportation of the slave between monitoring sites.

The existing software was modified to allow for inclinometer readout on channels 4 and 5, which previously were dedicated for voltage readings of the batteries. Therefore only the condition of the telemetry battery is being monitored on channel 6, while the batteries that provide power to the slave's microprocessor system are not monitored any longer. This, however, should not cause problems, because the telemetry battery will always be the first one to discharge. Since all batteries are charged simultaneously through the same charging port, there will always be sufficient power for the microprocessor systems as monitoring of the critical telemetry battery continues. Further software modifications resulted in providing screen inclinometer readings directly in one hundredths of a foot per length of the inclinometer (2 feet), as requested by Syncrude personnel.

4. TRANSMISSION IMPROVEMENTS

4.1 Relay Testing

Rather than purchasing more powerful transmitter-receiver units, which was not feasible within the financial constraints of this contract, it was decided to equip each slave unit with an antenna relay, thus utilizing the existing directional transmission antennas for alternate transmission and reception. The relays were acquired and thoroughly tested in the laboratory as well as under operational field conditions prior to installation on the site.

4.2 Field Installations and Testing

Once the Consultants were satisfied that the new relays performed well, the following installations were carried out at the Fort McMurray site.

- Installation of new antenna relays on slaves No. 4, 6, and 7.
- Installation of a new antenna relay at the master station.
- Calibration of the transmitter frequency for the three slaves as well as for the master.
- Installation of temporary heaters in both the receiver and transmitter enclosures of slaves No. 6 and 7. These heaters can be activated manually when the temperature falls below -10°C as it appears that the RF link causes transmission problems at these low temperatures.

With these installations, the data transmissions worked error free for distances beyond 5 km.

During a maintenance trip to Fort McMurray in January 1987, an overnight systems test was conducted between slave No. 6 and the master station without activating the heaters in spite of a -8°C temperature. While the transmissions worked satisfactorily and no data errors occurred, an LRC transmission error was detected whenever the temperature dropped below -6°C.

A frequency test on the RF link was conducted on both the master and slave stations. The master transmitter showed a 100 Hz drift while the slave transmitter showed an 800 Hz drift. Although this was not enough to cause a data error, the frequency shift at the slave did account for the transmission error. The amount of frequency shift that occurred is not unusual when one considers the time elapsed since the last frequency calibration (approximately 5 months), as well as the extreme temperatures to which the slave unit had been subjected during this time span.

Once the slave transmitter was recalibrated, no further transmission errors were detected, and further tests insured data and channel integrity.

5. SYSTEM MAINTENANCE

5.1 On-Site Visits by ERCL Personnel

During the span of this contract, ERCL personnel conducted on-site visits amounting to 6 may-trips, all duly authorized by the Scientific Authority.

A. Makosinski travelled on 16 August 1986, while A. Chrzanowski and A. Zielinski, who was sent in place of B. Kurz, travelled together on 19 August 1986. This provided several days of overlap between these visits.

All three consultants were on hand for the final on-site visit to Fort McMurray, commencing on 26 January 1987.

5.2 Response to Syncrude Field Testing Recommendations

Extensive field testing of the CANMET tiltmeter/telemetry system was carried out by Syncrude personnel during the period of December 1985 to August 1986 (see Syncrude Canada Ltd., inter-office correspondence, dated 14 August 1986, a copy of which is given in Appendix I).

The Consultants were asked to respond and/or act on the conclusions and recommendations which resulted from this test program. The Syncrude statements and the respective responses are listed in the order of the Syncrude memo.

(1) Slave stations were not operational in temperatures below -20°C and therefore will require environmentally protective covers to maintain the internal temperature above this lower limit.
Response: Tests indicate that the RF link causes transmission problems at these low temperatures. Therefore, temporary heaters were installed in both the receiver and transmitter enclosures as well as near temperature sensitive components on slaves No. 6 and No. 7. The heaters can be activated manually when the temperature falls below -10°C. When the heaters are "ON" continuously, batteries need to be recharged no less than once a week.

(2) When the system is required to autostart, normally due to power interruptions, the program automatically reverts to recording its programmed date which is 01-01-80. For reference purposes, the system must log the actual start-up date, and not the programmed one.
Response: If a CALENDAR/CLOCK card is purchased and inserted into one of the slots of the IBM-PC, the correct date will be stamped onto each file, thus eliminating the identification problem. Such a CALENDAR/CLOCK card was installed in January 1987 in the IBM-PC and also the memory was expanded by an additional 64K bytes. There is further room on the card for another 320K of memory should future applications require it. The presence of the battery backed clock eliminates the need to enter the date at the beginning of the program sequence. The telemetry software was modified to read the clock.

(3) When the system's program was changed, it will read on the programmed interval once before reverting to a continuous monitoring mode. This continuous mode will remain in effect until 23:59 hours, at which time it will return to monitoring at its originally programmed interval. Once the system has started the continuous monitoring mode, the computer must be shut off in order to reprogram the scanning interval.
Response: This error did not occur when the Consultants' program disk was used. It appears

that there was a malfunction in the disk available to Syncrude. Once the disk was exchanged in January 1987, this erorr did not occur any longer. Tests extending well beyond 24 hours confirmed this.

(4) Operating problems are often indicated by screen error messages such as 5-565, 5-580, 5-572, 5-590. These messages are only indicated on the screen and are not printed out, thus being lost if the system resumed monitoring.
Response: These are IBM system error messages in BASIC. The first number represents the error code (see IBM Manual), the second number indicates the line in the program where the error occurred. A small software change would cause these messages to be printed, if desired.

(5) Instruction manuals were not included with the system, therefore any problems which occurred were difficult to solve, if solved at all.
Response: The final ERCL report 1983 contains an operation manual for the entire system (pp. 96-113). Furthermore, additional details were provided to the Scientific Authority in the form of flow charts. Finally, a "Quick Guide to ERCL Telemetry Software and Hardware" is included in Appendix II of this report.

(6) The system test message fell to 2.38, which was below the recommended 2.40-2.60 range. No reason was identified for this drop.
Response: The system test message can fall to 2.38 (slightly below the recommended range of 2.40 to 2.60) without adverse effects. It is, however, an indication of a possible analogue/digital conversion problem and thus should be adjusted.

(7) Tilt readings fluctuated with temperature readings.
Response: The fluctuations of tilt readings by ±40 mV are caused by the limiting resolution of the analogue to digital conversion of the system which is 1 bit. With a total range of ±128 bits for ±5 V this represents ±40 mV/bit. The observed fluctuations were within the resolution range.

(8) Tilt readings fluctuated during repetitive scans, possibly due to wind effect, which would indicate the tiltmeter system to be too sensitive for this environment.
Response: See Item 7 above. If the fluctuations are larger than the resolution then it is indeed an indication that the tiltmeters are too sensitive.

(9) Slave batteries required a minimal recharging schedule for this program.
Response: This is not surprising, as the system was designed to be extremely energy efficient.

5.3 Additional Field Tests and Maintenance Operations

A number of additional maintenance operations and field tests were carried out during the on-site visits:

- As already mentioned, the antenna mast for slave No. 6 was replaced.
- A surge protector was installed on the computer power line.
- A 24-hour systems test was conducted in January 1987 using slave No. 6 together with an inclinometer. An LRC transmission error was detected and corrected (see section 4.2 of this report).
- Slave No. 6 was subsequently taken to the mining site and set up together with an inclinometer placed in a borehole near the dragline. The inclinometer data were first measured with a digital meter, then with the SINCO RPP unit. Both readings were then compared to the readings transmitted to the main office via the telemetry link. With the exception of inverted polarities, the screen data matched both measurements to within ±1 significant resolution bit. Signal reception was excellent, and no transmission errors occurred. Syncrude personnel continued the tests for another month and reported excellent results for all operational aspects of the system.

5.4 Debriefing Seminar

In conjunction with the final visit of the Consultants to the test site, a comprehensive debriefing seminar was held, as requested, on 27 January 1987. This seminar was attended by approximately 15 persons which included experts from CANMET, Syncrude, ERCL, as well as invited guests from other mining establishments.

Dr. N. Stewart from CANMET provided the general introduction to the project and gave a brief overview of previous projects connected to the present one. Dr. A. Chrzanowski reviewed the present state of the art in monitoring surveys and highlighted the progress made in recent years, both in technology and in methodology. Mr. A. Makosinski reported on the improvements that have been incorporated into the telemetry system and presented the results obtained with them. Dr. A. Zielinski outlined future expansion and automation possibilities for telemetric data acquisition and transmission.

These presentations were followed by a lively discussion session dealing with details of present and proposed systems.

6. ENHANCEMENT POSSIBILITIES FOR A NEW GENERATION TELEMETRY EQUIPMENT

The study of current and future desirable capabilities of telemetry systems is divided into four aspect groups. These groups encompass aspects of the environment in which the telemetry systems operate, the interface to and interactions with the users, the operational capabilities of the systems, and the implementation of hardware and software.

All recommendations and conclusions are based on current state of the art technologies and methodologies with member components and methods available now or in the near future. The resulting technical and operational enhancements are applied to the existing CANMET telemetry system, a familiarity with which is assumed.

6.1 Environmental Aspects

By nature, telemetry systems are mainly used in an environment where data collecting by other means would be inconvenient, hazardous, or simply impossible. This often requires long-term operation, reliability, and unmanned operation in adverse conditions.

(a) Long Term: Miniaturization using very large scale integration (VLSI) devices reduces power consumption over discrete components. Sample versions of entire microprocessor controlled intelligent data acquisition devices are available today (e.g., Motorola 68HC11, Hitachi 63701) which replace in one chip three of four modules of the CANMET telemetry system (MPCU, DAQM, TELM (partly)). Implemented in CMOS technology, they exhibit an energy consumption of approximately 10% (in operation) and <1% (in stand-by mode) when compared with the existing telemetry system. Consequently, batteries of one-tenth or less of the capacity of the current ones will suffice for a one-year lifetime.

(b) Reliability: The use of VLSI devices increases hardware mean time between failures (MTBF) as interconnection problems are eliminated. Operational reliability is increased by better link protocols, and error detection and recovery, made possible by faster processors with more memory for more intelligent software.

(c) Unmanned Operation: This requires long-term and reliable operation. In addition, robust operation is needed which implies automated recovery from expected problems. The key requirement is larger computer power with self-diagnostics and remedial actions. Examples include switching to redundant power sources (solar cells), fall-back emergency data link at lower speed, and automated detection and compensation for (or calibration of) misadjusted sensors/analogue converters.

(d) Adverse Conditions: Telemetry systems must operate in extreme physical conditions and hazardous areas. Modern military components in CMOS technology operate reliably from -55°C to +125°C ambient temperatures. Smaller power consumption means less self-heating effects, thereby increasing the upper temperature bound. Dangerous areas (gas) prohibit the use of hot devices or sparking contacts. Miniaturized telemetry systems lend themselves to full air-tight encapsulation and safe operation. Optical cable and infrared (IR) wireless links are available (cable to 10 km, wireless to 200 m line of sight) which cause no environmental contamination of stray energy as do electromagnetic radio links. Electric cable links with a central power source avoid remote batteries which are fume-prone, but with the added danger of electrical sparking when cables are cut.

Operation at remote sites and/or in adverse conditions implies transport to and storage at these sites. A dramatic reduction in volume from the current two-box telemetry system is possible by the miniaturization. This implies tighter packaging, lighter in weight, and allows for sturdier and better insulated housings. A total volume of 0.5 to 1 cubic foot, including batteries, is possible.

(e) Service of the System: State of the art electronic instruments are serviced on a board-swapping basis. Individual components are replaced in the lab, if at all. This service is field-proven and can be handled by trained users. The high complexity of modern telemetry systems calls for special service methods. The available intelligence of microcomputer-based systems allows for automated self-diagnostics on site. Remote servicing of the telemetry system can be implemented by means of a public carrier network world wide (telephone, Datapak) for more difficult service problems. Telemetry slave and master emulators are feasible to isolate on site or via a link faulty or temporarily misfunctioning system units by automated long-term tests.

6.2 User Interface

The aspect of the interaction of users with modern telemetry systems underwent probably the biggest change among all the other aspects. This is contributable to the immense increase in computer power available for other than telemetry data exchanges, mainly in the telemetry system's master station. Ergonomy and user-friendliness are addressed here.

(a) User Interaction: Modern telemetry systems should be turn-key systems with default configuration and immediate operation by novice users. To allow for exploitation of their full power, the system utilities should be useable in hierarchical order. Novice users need not get involved with difficult system configurations, whereas expert users benefit from progressively complex utilities.

All user interaction nowadays is performed on a full-screen basis on monitors using either keys or ikons. All interaction is in the form of prompt/reply sequences with help functions and entry error detection with retry capability. The shell of the system control program which defines the user interaction is hardware independent, so that hardware upgrades are transparent to the user operation.

(b) User Applications: A telemetry system is generally used for many different applications. The control system software supports only the basic data collection and data preprocessing activities. Application specific programmes are to be added by the user. Standard language interfaces make this addition an easy task. Well-defined user call functions do not require the source code of the control system software to be available or inspected by the user. Plenty of computer power allows for the addition of on-line graphic computations and data interpretation for on-site inspection of the data collection progress.

(c) Remote Access: The wide availability and standardization of comon carrier networks and specialized data transport services make remote control of the telemetry system (via telephone, Datapak, etc.) a desirable feature. On-line and off-line interrogation of the telemetry system make collected site data immediately available in the user's office anywhere in the world.

6.3 Operational Aspects

The internal operation of a modern telemetry system is described and recommended properties are outlined.

(a) Reporting: The reporting on-demand as employed by CANMET telemetry system is the most advanced one and needs no enhancement. A software interface to user programmes can be

provided which would allow the data analysis programmes of the user to alter the reporting intervals in order to allow for trend analysis with adaptive reporting. To enhance this reporting method, multi-grouping of slaves with independent reporting intervals per slave group will allow several events to be telemetrically supervised. Thus the telemetry system serves as several independent systems in one.

An alarm feature is highly desirable, whereby the slaves test for sensor signals exceeding a threshold. They alarm the master station by an escape of the regular reporting method. The threshold can be set after interrogation to avoid successive alarms.

The operation of the quasi-simultaneous slave reporting of modern telemetry systems should emply one of the newer protocols of local area networks, rather than the classic type of poll-transmit data-acknowledge session per slave. The variable time-slot or token-passing protocols are to be considered, perhaps with priority. This would greatly speed up the interrogation of slaves an expected 420 sec (7 min) for 256 slaves as compared to the current 50 minutes.

(b) Preprocessing: The non-continuous sampled interrogation of sensor data enforces an upper limit on the spectral component the collected sensor signal can have. To avoid aliasing and spectrum distortions due to uncontrollable sensor excitements, a preprocessing filter would be beneficial. Other preprocessing to be carried out may include simple averaging, robust averaging, and predictive averaging with trend reduction. All preprocessing is done in the microprocessor-based slave units to remove computational load from the master station.

(c) Sensors: A total of 16 analogue channels are available with two channels used for slave internal self-tests (ADC conversion and battery test). In view of the newest VLSI intelligent data acquisition systems, a unipolar analogue input 0 . . . +5V with 10 bits resolution (10^{-3} accuracy and resolution) is advisable. Older types of sensors with bipolar output can be adapted via unity-gain amplifier circuits. Additionally, a digital 10-bit input can be considered as future sensor devices will likely be of the digital type with A/D-conversion built in, if necessary. All sensors are powered up when needed to save energy consumption. The allowed settling time is adapted to the ambient temperature. This avoids the design for worst cases and saves additional battery energy.

(d) Security: The slaves are to be protected with enhanced self-tests and fault diagnosis, along with fall-back emergency power (solar cell) and a low-speed data link in case of excessive external interference. Compact data messages with an extensive error detection capability are used. At the master station, dual back-up files with alternate use protect against data loss. An uninterruptable power supply (UPS) can be used for the central station if power brown-out and outages are a problem.

6.4 Hardware Implementation

Many of the enhancements of the telemetry system mentioned in the previous three sections are reflected in the hardware implementation.

(a) Electronics: The advantages of state of the art microcomputer chips have been outlined in section 6.1.

(b) Data Link: Optical cable links provide the best protection from external noise sources and need no special modulation methods for medium distances (1 km). Radio and IR links require noise-insensitive modulation techniques to combat noise. A single or dual level modulation is advisable employing FM or PM carrier modulation. The option of narrow-band or wide-band transmission is to be considered (3 kHz/20 kHz bandwidth). At the higher bandwidth, data can be

sent about six times faster which is desirable for several hundred slave units.

(c) Power: The slaves are generally powered by batteries. The use of modern integrated circuits and other measures mentioned above allows for a dramatic reduction in battery capacity. A single battery, instead of 3 or 4 individual ones, is recommended with a power-booster for transmitter operation during short periods (<1 sec).

(d) Construction: Smaller size facilitates the packaging of the new telemetry system. A modularized construction is preferable with multi-purpose boards employed in both slaves and master units. Diagnostic utilities, such as external monitors and internal diagnostic software routines, accessible via field terminals, allow efficient service of the system.

7. CONCLUSIONS AND RECOMMENDATIONS

As evident from this report, all tasks specified in the contract and the Consultants' proposal have been successfully completed. Borehole inclinometers can now be connected to any of the slaves, thus replacing tiltmeters. It does require some software changes to use new conversion parameters, but this can easily be done.

As demonstrated with one slave, the present slaves can accommodate up to 6 sensors after some minor hardware changes. One of these sensors is usually a temperature sensor.

The transmission capability of the present system goes well beyond 6 km, provided that there is direct visibility between the stations. If this is not the case, or if the transmission distances significantly exceed 6 km, then more powerful transceivers need to be built into the units.

The operation of the system at temperatures below -20°C cannot be guaranteed. The heaters that were installed have to be switched on manually, which is not very convenient and reliable. Larger modifications would be required to completely solve this problem, e.g., thermostat controlled heaters, which also require more power.

Rapid technological progress within the past 6 years, in areas such as microprocessor technology, is also making an impact on telemetric data acquisition. Thus the Consultants would like to state that further modifications of the present system, to adapt it to perhaps yet another task, can no longer be economically justified. As recommended in the debriefing seminar, it would be less expensive and more efficient to build a new system.

As far as the specific application at Syncrude's oilsands mining operation is concerned, the problem lies not only with telemetric data acquisition but rather there is a need for a full automation of the whole surveying procedure, so as not to cause any further costly interruptions of the dragline operation. The Consultants feel that they are capable of designing and constructing a fully automatic survey-robot combined with a telemetry system to meet the monitoring requirements of a dragline operation.

8. References

Ecological and Resources Consultants Ltd. (1980). Development, installation and operation of a subsidence monitoring and telemetry system Final contract report submitted to CANMET (DSS File: 185Q.23440-8-0-16, contract serial no. 0SQ78-00238).

Ecological and Resources Consultants Ltd. (1983). Maintenance, construction and installation of an additional system, and research on further improvements and extended applications of the subsidence monitoring and telemetry system. Final contract report submitted to CANMET (DSS File: 18SQ.23440-1-9131, contract serial no. 0SQ82-00051).

Ecological and Resources Consultants Ltd. (1986). Field adaptation of telemetry instrumentation in surface oilsands mines. Final contract report submitted to CANMET (DSS File: 145Q.23440-5-9076, contract serial no. 0SQ85-00116).

APPENDIX I

SYNCRUDE CANADA LTD.
INTER OFFICE CORRESPONDENCE

TO: George Holmes REF. NO.

FROM: Terry Stevens DATE: August 14, 1986

SUBJECT: CANMET TILTMETER/TELEMETRY UPDATE

This report is intended to provide a brief summary of the progress of the Canmet tiltmeter/telemetry test program established on site in co-operation with the Geotechnical Engineering Section.

The system was originally designed to provide a method of continuous remote monitoring of surface movement, via FM transmission, from slave stations located in movement areas.

OBJECTIVES

The main objective of this test program was to determine the reliability of the telemetry system over an extended time period.

The tiltmeters would only be used as monitoring devices for testing the telemetry system, awaiting a telemetry design which would link it to our present inclinometer monitoring program, as past surface monitoring equipment studies have indicated their unsuitability for Syncrude's mining environment.

FIELD TESTING

The computer assisted control station was located in 41 A building, with two slave/tiltmeter stations located adjacent to inclinometers installed to a depth of 80 feet on the S-2 dump.

The S-2 dump provided an ideal test location as it was beyond the mine transmission distance required, was isolated from operations heavy equipment influence, and was located on a continuous movement zone approximately 50 feet below surface.

The system was started in December 1985 and was monitored, to date, for problems which occurred during this test period.

Because of the system downtime which occurred, and our unfamiliarity with troubleshooting the equipment, we were unable to compare tiltmeter readings to actual slope inclinometer data.

CONCLUSIONS AND RECOMMENDATIONS

During this test program (December '85 - August '86), a number of observations and recommendations were concluded, and are listed as follows:

- o Slave stations were not operational in temperatures below - 20° C and therefore will require environmentally protective covers to maintain the internal temperature above this lower limit.

- o When the system is required to autostart, normally due to power interruptions, the program automatically reverts to recording its programmed date which is 01-01-80. For reference purposes the system must log the actual start up date, and not the programmed one.

- o When the system's program is changed, it will read on the programmed interval once before reverting to a continuous monitoring mode. This continuous mode will remain in effect until 23:59 hours, at which time it will return to monitoring at it's originally programmed interval. Once the system has started the continuous monitoring mode, the computer must be shut off in order to reprogram the scanning interval.

- o Operating problems are often indicated by screen error messages such as 5-565, 5-580, 5-572, 5-590. These messages are only indicated on the screen and are not printed out, thus being lost if the system resumed monitoring.

- o Instruction manuals were not included with the system, therefore any problems which occurred were difficult to solve, if solved at all.

- o The system test message fell to 2.38, which was below the recommended 2.40-2.60 range. No reason was identified for this drop.

- o Tilt readings fluctuated with temperature readings.

- o Tilt readings fluctuated during repetitive scans, possibly due to wind effect, which would indicate the tiltmeter system to be too sensitive for this environment.

- o Slave batteries required a minimal recharging schedule for this program.

TS/ss

APPENDIX II

QUICK GUIDE TO ERCL TELEMETRY SOFTWARE AND HARDWARE

STARTING UP
SELECT AND/OR CHANGE OPTIONS
SCANNING AND READING THE SENSORS
CHANGING CALIBRATION COEFFICIENTS AND CHECKING MAINTENANCE
STATISTICS
ERROR MESSAGES
DISK MANAGEMENT
HELPFUL PC COMMANDS
ERCL HARDWARE

STARTING UP

To start the system, turn **ON** the Master station by pressing the yellow pushbutton switch. Then insert the disk into the drive on the IBM PC and turn **ON** the computer by flipping the red switch on the rear right of the PC enclousure. The STANDBY menu will appear on the screen:

```
***** COMPUTER CONTROLLED TELEMETRY/MONITOR SYSTEM *****
        ERCL   FREDERICTON, N.B.  VERS2.0   JUNE 1983

OPTIONS IN EFFECT:
     SLAVES IN SCAN: 5 6 7
     REPETATIVE SCAN 60 MINUTES: ACTIVE
     PRINTER LOG  ON     DISK BACKUP ON
     REMOTE CONTROL  OFF

LAST SCAN STARTED: 11-27-1985 / 19:05    -   PAUSE 60 MINUTES

STANDBY        PRESS SP FOR COMMAND MENU      11-27-1986 19:07
```

The menu selections can be explained in the following examples:

[SLAVES IN SCAN: 5 6 7] - Indicates which Slave Stations have been selected for scanning. Each slave station has been assigned a number. Here, Slaves #5 , #6, and #7 will be scanned at intervals.

[REPETETIVE SCAN 60 MINUTES: ACTIVE] - Shows if repetetive Slave Station scanning has been selected and the period between scans. ACTIVE - indicates that the program is running.

[PRINTER LOG ON] - If printer log has been selected, data will be automatically printed out after each scan. If the printer has been disconnected, the program will wait for one minute, after which it will ignore the LOG ON command and continue.

[DISK BACKUP ON] - If disk backup has been selected, data after every scan will be automatically recorded on the disk file named "BACKUP".

[REMOTE CONTROL OFF] - If ON, enables access to the remote operation of the Master Station.

Also shown is the date and time of the last scan and the length of the pause. Changes in any of the settings as well as full operation of the Master Station is carried out from the COMMAND menu which can now be accessed by pressing the [SPACE BAR].

SCANNING AND READING THE SENSORS

To start the Slave scans press key (S). The Master Station will proceed to interrogate the Slave Stations as per selected configuration.
After scans of Slave #5, #6 and #7, the following may appear on the screen:

```
SCAN STARTED  DATE: 01-22-1987   TIME: 01:15   REPETATIVE SCAN 5 MIN

          TIME  ID  CH0   TILTA  TILTB  TEMP  INCLA  INCLB  +VB3  TEST
CALL 5   01:15   5  0.00   1021    567   5.0  12.11  19.00  12.0  2.50
CALL 6   01:20   6  0.00   3584    600   5.1  12.15  15.15  12.0  2.50
CALL 7   01:25
      TIM CALL
      TIM CALL
      TIM CALL
DIAGNOSTIC -192  4.96   4.96   4.96   4.96   4.96   4.96   4.96  4.96

 MAINTANACE STATISTICS   DATE: 01-22-1987   TIME: 01:15
 TIME OUT  7(3)
 TLT A LIMT 6(1)
 PERM ERROR 7(1)
 ORIG.CALLS 5(1)  6(1)  7(1)
```

Slave 5, 6, and 7 were called. Slave 5 and 6 replied with data. Slave 7 did not reply and **TIM**ED **OUT** after three attempts. This and other problems are shown in the maintanance statistics section. Channel A of the tiltmeter reached its maximum possible reading and should not be used. The fact that no data was received from 7 is also shown as a **PERM**ANENT **ERROR**.

A system diagnostic (-192 4.96 4.96 4.96 4.96 4.96 4.96 4.96 4.96) indicates the internal slave I.D. number (-192), followed by a self test of the Master software on all eight channels.

There are eight channels available for sensors. Prior to August 1986 channels 4 and 5 were used to monitor internal ±12 volt batteries used for the digital circuitry. These two channels were then modified to accept inclinometer inputs. Channel 6 still monitors VB3 which is the RF link battery, and the one which always goes down first. When VB3 reading falls below 10 volts its time to recharge the Slave batteries.

CHANNEL ASSIGNMENTS AND READINGS

	UNUSED	TILTA	TILTB	TEMP	INCLA	INCLB	+VB3	TEST
CHANNEL #	0	1	2	3	4	5	6	7
RESOLUTION ±		28	28	.3	.15	.15	.12	.04
MAX. READING ±		3584	3584	40	20	20	15	4.96
UNITS		Seconds		°C nom.	1/100ft per 2ft.		Volts	Volts

Readout variation of ± 1 resolution are not significant. Channel 0 is not used.

ERROR MESSAGES

User replies error messages appear in bottom right of the screen (line25)

ILLEGAL	Illegal command entered
INVALID	Invalid data entered

Slave scan errors appear next to the CALL information on the upper part of the screen:

INC A LMT	Inclinometer A range exceeded (reading volts >4.5) *
INC B LMT	Inclinometer B range exceeded (reading volts >4.5) *
+VB3 LOW	Battery #3 voltage low (less than 10.5v)
ADC TEST	Self test in Slave failed (reading shold be >2.42v or <2.58v)
TIME OUT	No Slave response (time ≥30 sec.)
TIM-S OUT	Slave response incomplete (time ≥30 sec.)
LRC ERROR	Transmission error detected
OVERFLOW	Slave response too long
CTS ERROR	No CTS signal (COM1) for telemetry link
PERM ERR	After several retries, no correct reply from Slave
TEMP LIMIT	TEmperature range exceeded (<-25°C or >40°C)
ORIG.CALLS	Number of original calls (not retries) to Slave (This is not an error message but is useful for problem detection.)
ERROR8	Internal Slave errors
ERROR9	Internal Slave errors

User related error messages due to hardware or software problems are intercepted and listed on the bottom right of the screen (line 25):

***** SYSTEM ERROR**: ee/llll

ee	BASIC error number
llll	Line number in BASIC program

Two errors are especially identified by warnings:

ee=24 or 27	Printer not available and printer disabled
ee=61 or 71:	Disk not available and BACKUP disabled.

* not implemented

To make a backup copy of the disk, get first into DOS by typing **system**, RETURN key, then type **diskcopy a: b:** RETURN key, and follow screen prompts.
Renaming a file can be done from Basic. This example changes "Tele31.bk" to "Tele31.bas". A>**rename tele31.bk tele31.bas**
Both of these commands may not be on the ERCL disk and have to be loaded from the original IBM DOS 1.1

To erase a file type;
A>**erase** (name) RETURN key.

TELE31 is an open file. Listing can be done by (x) exiting from COMMAND menu and typing **list**.

In "Tele31", channel 4 and 5 unit multiplicand of 4.1 is found in line # 3050. Printout format is set up in line 1140.

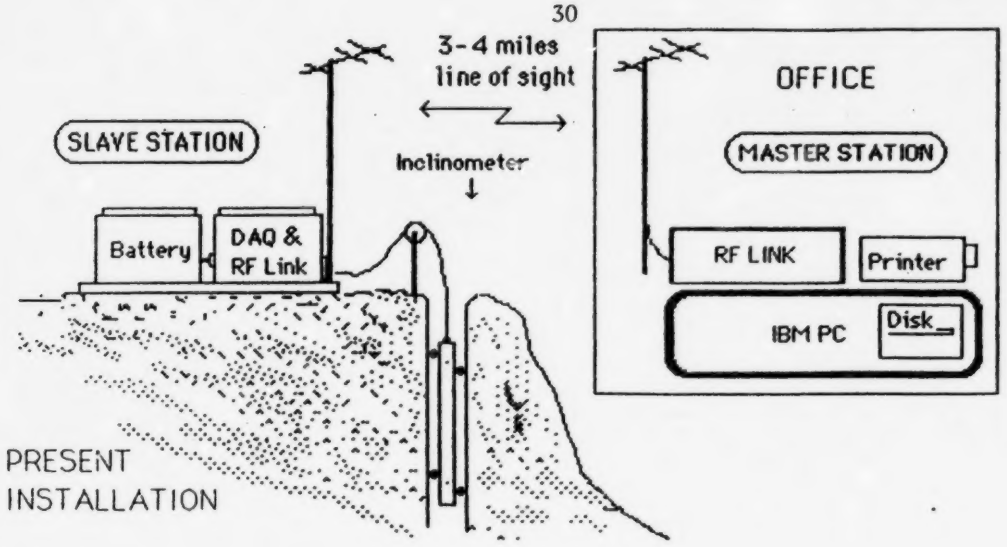
The program can be used on IBM clones loaded previously with GW Basic.

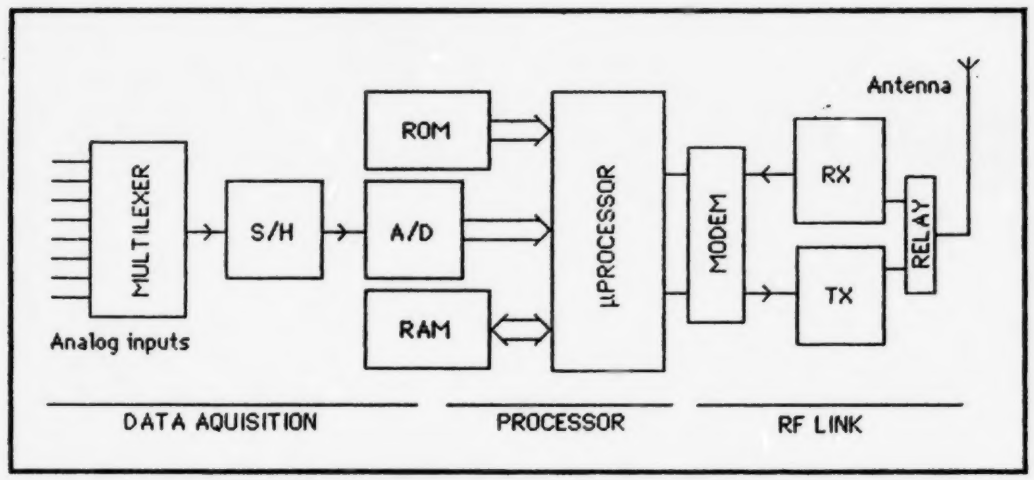
(CONT)(ALT)(DEL) Resets the program and the computer. Pressing (ESC) steps back the last entry.

Detailed description of the program functions can be found on page 93 - 113 of ERCL Final Report, Dec 1, 1983. Original software was designed to run on an early IBM Personal Computer using DOS 1.1, with a minimum of 64k of memory, a single sided double density 160k diskette, a parallel port, two asynchronous serial ports, a printer, and a calendar card (installed - Jan 87, also memory expanded to 128k). The ERCL telemetry and control electronics connect to the parallel port and one of the serial ports, the other is left for remote control operation as well as optional use for accessing the public telephone system via a modem.

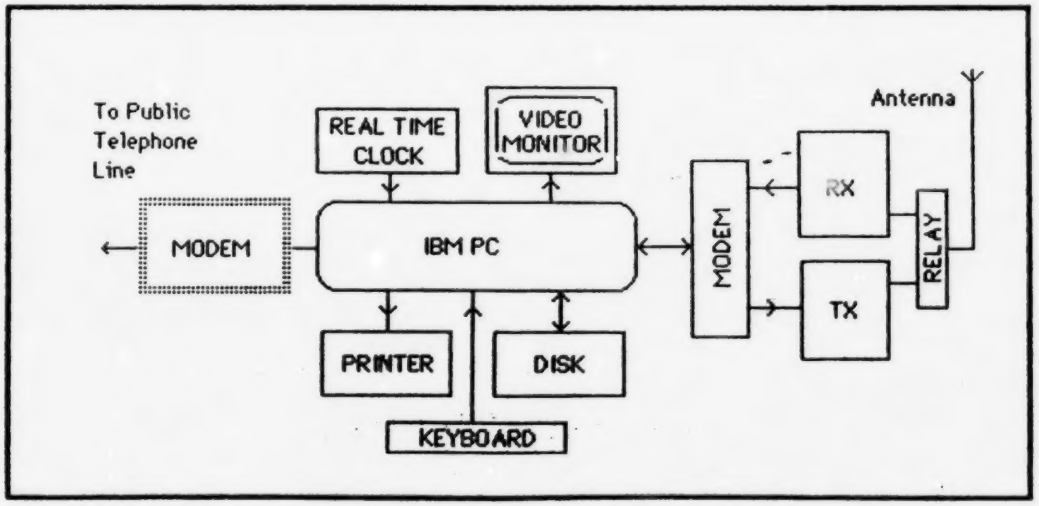
In case of difficulties call the author of the program, Dr. Bernd Kurz; 506 453 4566 - day, 506 455 3113 - evening, or Art Makosinski; 506 454 4724 - day, 506 454 6212 - evening.

December 1986.
A.M.

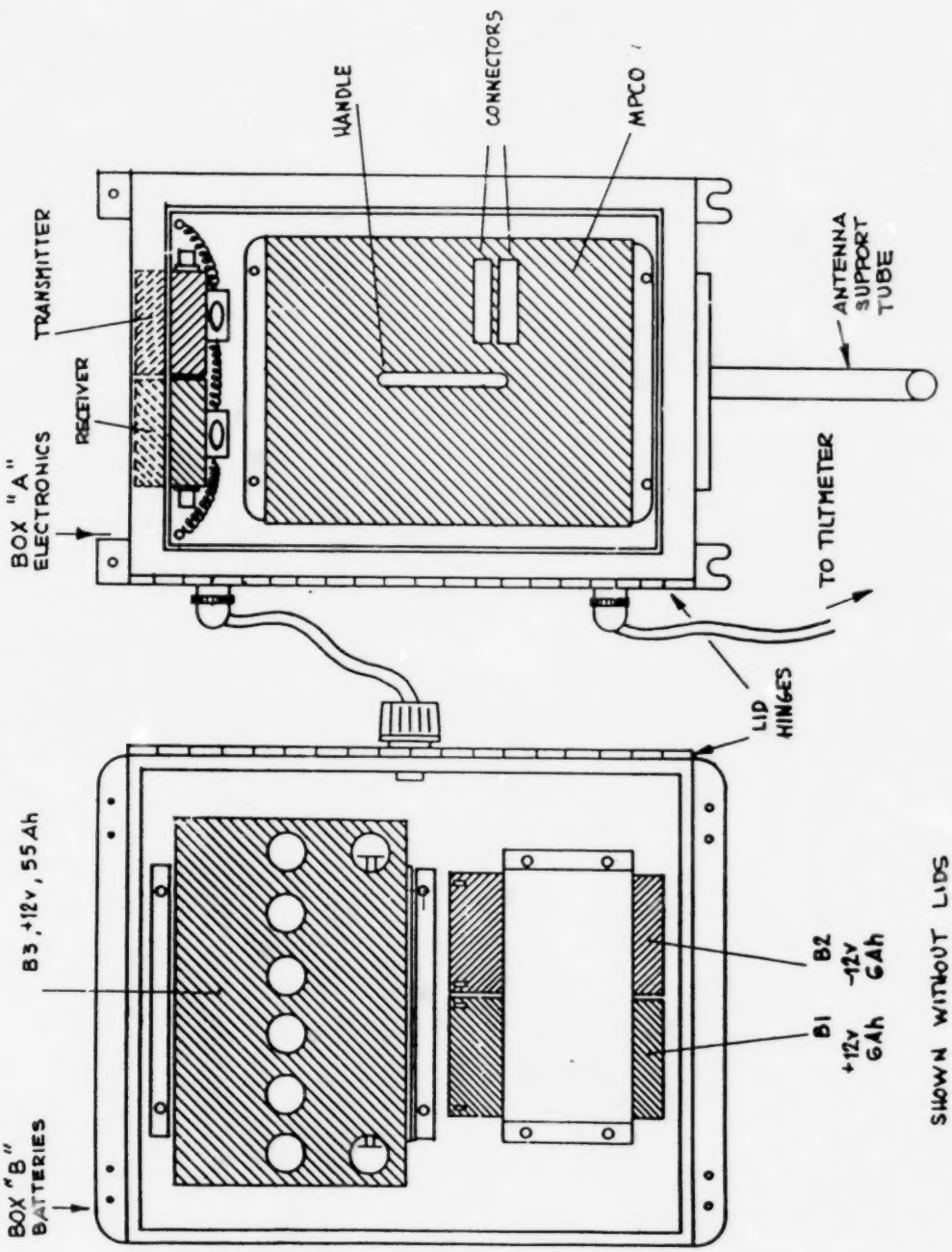




SLAVE STATION - Responds to interrogation of the master with inclinometer and maintanance data.



MASTER station: Receives data, stores it on a disk


HANDLE
CONNECTORS
MPCO
TRANSMITTER
RECEIVER
BOX "A" ELECTRONICS
ANTENNA SUPPORT TUBE
TO TILTMETER
LID HINGES
B3, +12v, 55 Ah
B2 -12v 6Ah
B1 +12v 6Ah
BOX "B" BATTERIES
SHOWN WITHOUT LIDS

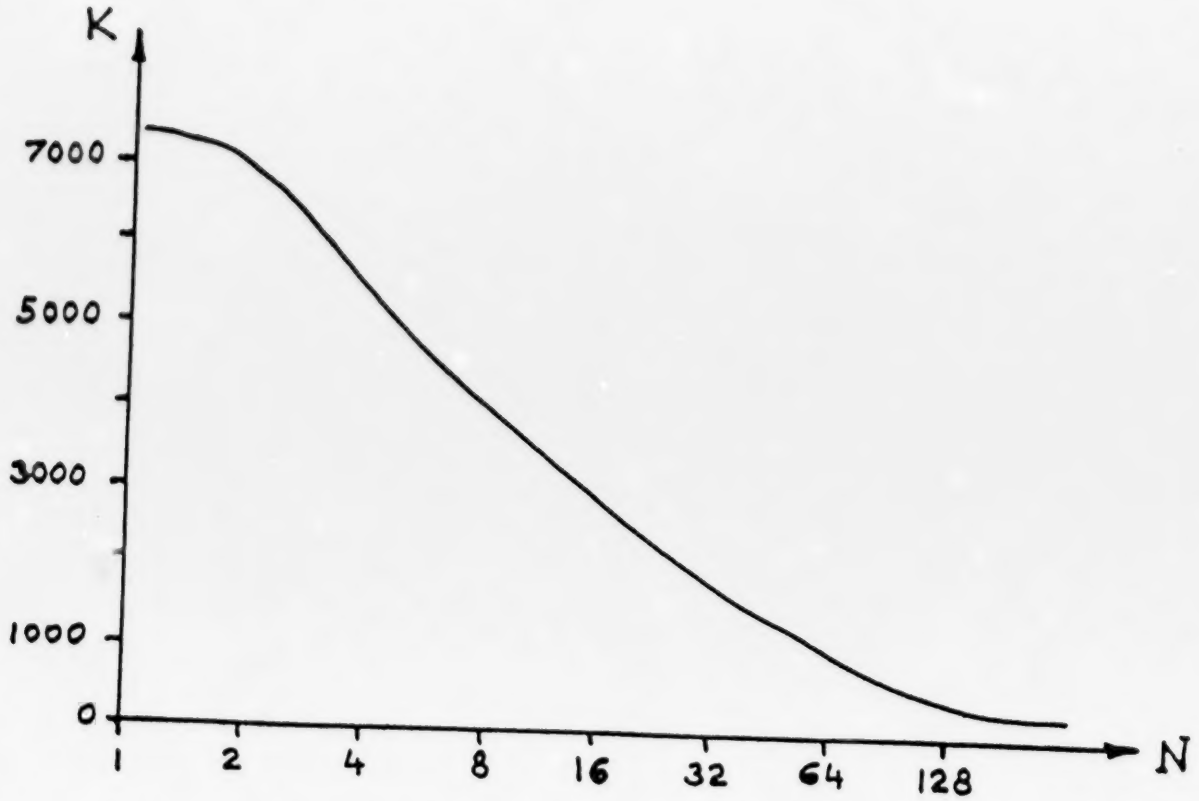


FIG.7. Battery Lifetime in Terms of Number (K) of Interrogations and Number (N) of Slaves at an Average Temperature of + 5°C.